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To reduce energy consumption and to maintain rapid economic growth: Analysis of the condition in China based on expended IPAT model

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ABSTRACT

As one of the important driving forces of world economic development, China's rapid economic growth has not only supplied the world with a large number of manufactured goods, but also caused China's sustained and rapid increase in energy consumption because of the characteristics of China's economic development and overall low productivity derive from them in many years. According to the IPAT model and its expansion, this article figures out China's indicators of economic growth and changes in energy consumption brought by technological progress since 1986. Empirical results show that, despite many years' efforts, China's high-speed economic growth is still largely dependent on massive energy consumption. How to maintain rapid economic growth while reducing energy consumption? China has faced the very problem it needs to address.

Contents

1. Introduction

In the past 30 years of reform and opening up, China's economy and society have undergone surprising changes. Its GDP is 364.5 billion RMB in 1978, while in 2009 it has soared to 33.5353 trillion RMB, of which the share of total amount of the world economy has increased significantly. In spite of the rapid economic development, China has paid for enormous resources and environmental costs, and severe energy shortage and environmental pollution have become the bottleneck to the continuing rapid development of China's economy. To reduce energy consumption has become an important guarantee for China's sustainable economic development, which is the inevitable choice for the construction of a resource-saving and environment-friendly society as well.

At present, the process of industrialization in China being still far from completed and the construction of new industrialization having just started, China will have to continue to promote industrialization under the constraint of resources and environment. In the meantime, constraints of resources and environment will push China to make more effective use of resources and implement clean

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production, and speed up upgrades of the labor-intensive section in the high-tech industrial chain. Thus, under the dual pressure of the change of resource conditions and the international community, it is necessary for China to study how to improve the quality of economic growth and get rid of the development mode of low-level production and pricing strategies to achieve higher ratio of input–output and performance-price than past through technological progression and management innovation. China's economic development is inevitable to face the trend of deep internationalization, in which it is an important way to enhance their competitiveness by enhancing the rate of economic growth while reducing energy consumption and pollution emissions.

This article will analyze the energy production, consumption and their elasticity brought about by economic growth from 1992 to 2008, in order to find the transformation track of China's energy consumption and its economic growth. Then according to the IPAT model and its expansion, China's indicators of economic growth and changes in energy consumption brought by technological progress are figured out since 1986, as well as its main problems existing in the process and some feasible measures of improvement.

The structure design in this paper is as follows. Section 2 is a literature review. Analysis of China's energy consumption is conduced in Section 3, which includes the status quo of energy supply and demand and efforts in reducing energy consumption in China. In Section 4, IPAT function and energy efficiency model is established, and an analysis is carried out based on this model. Policy recommendations are proposed in Section 5. The conclusions are shown at the end of the article.

2. Literature review

Many countries are very concerned about the improvement of the efficient use of energy and reduction of pollution emissions in China. Crompton and Wu [1] pointed that with an economy that is expected to maintain a rate of growth of 7–8% for decades, and that total energy consumption should increase to 2173 million tones coal equivalent in 2010, which is slightly slower than the average rate from 1990 to 2000. Kahrl and Roland-Holst [2] concluded that incipient structural changes in the Chinese energy economy and sustained economic and energy demand growth in China will pose important, and different, challenges for policymakers. Meidan et al. [3] developed an analytical framework for examining China's energy policy-making processes, and analysis the institutional limits to policy change and the constraints to implementation. Some scholars concluded that the domestic energy system in China can provide good economy and save energy significantly, while exergy analysis method, a powerful thermodynamic technique, may compare the exergy efficiencies of different energy consumption systems to show that the domestic energy system in China has the highest efficiency in energy conversion and make considerable contribution to energy saving of this country [4]. Zhao et al. [5] pointed that the decreasing trend of China's energy intensity has reversed since 1998 and the past few years have witnessed rapid increase in China's energy intensity, and low energy prices have directly contributed to high industrial energy consumption and indirectly to the heavy industrial structure.

Some Chinese scholars, from an economic point of view, analyzed the important for China to reduce energy consumption, and study the experiences to reduce energy consumption in developed countries, from which them put forward China's solutions. Shen [6] used the input–output model to calculate the effect of China's goods export and import on energy consumption in 2002–2005, by which the calculation showed that the effect of foreign trade on the whole economy is positive and that the energy saved by imports is more that the energy consumed by exports, which is conducive to domestic consumption of energy. By comparing the potential scales in China, Song et al. [7] selected Chinese regions as the basic unit of appraisement, and set up a appraisal indicator system to analysis the efficient and harmonious appraisal model of urban energy-saving and contaminant reduction. Wang et al. [8] concluded that there is a large emissions reduction potential exists in China's road transport sector, and that vehicle technology improvement may be the most effective means to meet emissions reduction targets. Zhang and Chen [9] analyzed the impacts of globalization on pollution with panel data of 33 industries from 2001 to 2005 and used PCSE robust estimation to find that there exists positive relationship between globalization and pollution, and China gains scale effect, technical effect, structural effect and factor endowment.

The vast majority of the above literatures focus on how to reduce energy consumption to achieve the harmonious development of economy–energy–environment by theoretical and empirical analysis, while statistical analysis of China's fast-growing economic and energy consumption is far less sufficient. The empirical analysis of reducing energy consumption and socio-economic development according to some indicators selected on the basis of classic model of sustainable development in China and the characteristics of Chinese energy and environmental problems will provide a reference for the accomplishment of reduction in energy consumption in China.

3. Analysis of China's energy consumption

3.1. The status quo of energy supply and demand in China

Just like capital and labor, energy, a fundamental driving force of modern economic development, has a major impact on accelerating the upgrading of productivity [10]. With the rapid economic growth, China's energy production and consumption have been inclined to growing at a high rate. Taking 1992–2008 as the sample spacing, the data of China's energy production and consumption showed that China's total energy production was 2.60 billion tons of standard coal in 2008, an increase of 1.42 times compared with the 1.07 billion tons in 1992. At the same time, China's energy consumption hiked up from 1.09 billion tons of standard coal in 1992 to 2.85 billion tons in 2008, an increase of nearly 161%. Judging from the absolute amount of energy production and consumption, China's energy production is insufficient to meet domestic consumption. There exists gap between supply and demand of energy and the trend of it is gradually expanding, say, 250 million tons of standard coal in 2007. Moreover, elasticity of China's energy consumption was very low in 1992–2001, during which the energy demand was lower in energy-intensive industries because the state conducted a large-scale consolidation to them. For instance, the elasticity coefficient of energy consumption is even below zero in 1997 and 1998. Subsequently, due to excessive growth of investment, the total social fixed assets' growth rate maintained at more than 25% for consecutive years. High energy-consuming industries, such as iron, steel, cement, chemicals and electric power, underwent rapid expansion; and energy consumption elasticity coefficient soared sharply, which was more than 1 in 2003 and 2004, that is, energy consumption growth rate was higher than GDP growth rate. The specific details are in Table 1.

Resource endowment, to a certain extent, determines that coal consumption has been dominant in the energy consumption structure in China. In 2005, China's coal consumption accounted for more than 68.9% share of energy consumption, well above the 25.1% of the world average. In the meantime, about one-third of China's coal consumption was combusted directly as the final energy, resulting in much more pollution on sulfide and carbon emissions. As a

Table 1
The energy production, consumption and their elasticity in China.

Year	Total energy production (million tons of standard coal)	Growth rate of energy production (%)	Total energy consumption (million tons of standard coal)	Growth rate of energy consumption (%)	GDP (billion RMB)	Growth rate of GDP (%)	Elasticity coefficient of energy production	Elasticity coefficient of energy consumption
1992	107,256	2.3	109,170	5.2	26923.5	14.2	0.16	0.37
1993	111,059	3.6	115,993	6.3	35333.9	14.0	0.26	0.45
1994	118,729	6.9	122,737	5.8	48197.9	13.1	0.53	0.44
1995	129,034	8.7	131,176	6.9	60793.7	10.9	0.80	0.63
1996	132,616	2.8	138,948	5.9	71176.6	10.0	0.28	0.59
1997	132,410	−0.2	137,798	−0.8	78973.0	9.3	−0.02	−0.09
1998	124,250	−6.2	132,214	−4.1	84402.3	7.8	−0.79	−0.51
1999	125,935	1.4	133,831	1.2	89677.1	7.6	0.18	0.16
2000	128,978	2.4	138,553	3.5	99214.6	8.4	0.29	0.42
2001	137,445	6.6	143,199	3.4	109655.2	8.3	0.80	0.41
2002	143,810	4.6	151,797	6.0	120332.7	9.1	0.51	0.66
2003	163,842	13.9	174,990	15.3	135822.8	10.0	1.39	1.53
2004	187,341	14.3	203,227	16.1	159878.3	10.1	1.42	1.59
2005	205,876	9.9	224,682	10.6	183217.4	10.4	0.95	1.02
2006	221,056	7.4	246,270	9.6	211923.5	11.6	0.64	0.83
2007	235,415	6.5	265,583	7.8	257305.6	13.0	0.50	0.60
2008	260,000	5.2	285,000	4.0	300670.0	9.0	0.58	0.44

Source: Calculated from "China Statistical Yearbook" (1993–2009).

consequence, environmental pollution and ecological imbalances are gradually serious.

3.2. China's efforts in reducing energy consumption

In China, reducing energy consumption has been put on the agenda in recent years. The government has made up objectives and policy measures of reducing energy consumption and encouraging the development of circular economy [11]. China's "Eleventh Five-year Plan" provides that China's total energy consumption should be controlled at around 2.7 billion tons of standard coal in 2010, that is, an annual increase of 4% on the basis of 2.25 billion tons of standard coal of the total consumption in 2005; and energy consumption of unit GDP should be reduced by 20%, from 1.22 tons of standard coal reduced to 0.98 tons, an average of annual 4.4%. Of sulfur dioxide and chemical oxygen demand (COD) and so, the total discharge of major pollutants reduced by 10%, an average annual 2.2%. In 2006, China's GDP growth rate was as high as 10.7%, 2.7% points higher than the original plan, while the plan of reducing energy consumption has not been accomplished. National energy consumption in this year is 2.46 billion tons of standard coal, and energy consumption of GDP per million is 1.17 tons of standard coal (lower 1.23%), an increase of 1.57% and 0.99% respectively than that of 2005. In 2007, the decline occurred compared with 2006 for the first time, the consumption decreased by 4.7% and 3.2% respectively. On the whole, energy consumption of unit GDP fell 5.38% cumulatively in the former two years and accomplished 26.9% of the planning objectives; emissions of sulfur dioxide and chemical oxygen demand, respectively, only achieved the planning goals of 32% and 22%, which means the aims of reducing energy consumption and pollution emissions were not fulfilled. In 2008, the situation has improved over the previous years, with the energy consumption of unit GDP falling 4.59% and COD and SO_2 emissions decreased by 4.42% and 5.95% respectively. The specific information can be referred to Table 2.

Although the descending of China's energy consumption and pollutant emissions shows good prospect, China's investment in pushing up economic growth could still result in increased investment of energy-intensive industries in the future, which in turn affect the goals of reducing energy consumption. Some people have paid close attention to the Environmental Kuznets Curve (EKC) and its "turning point" in China [12]. However, in the process of China's rapid economic growth, its achievement needs the responsibility of Chinese enterprises on environmental protection. Whether the "turning point" of Environmental Kuznets Curve will emerge in China or not, when it will come, and whether the local governments in china need to establish a series of policies to influence its process or not, are worthy of attention. Therefore, to analyze the relationship of China's economic growth and energy consumption is very urgent.

4. IPAT function and energy efficiency model

In order to further analyze the quantitative relationship of economic growth and energy consumption, this article employees expanded IPAT equation and energy efficiency model to carry out empirical analysis. Ehrlich and Holdren [13] proposed mathematical equations, including the relationship of environmental impact (I) with population (P), affluence (A) and technology (T), to study the relationship among economic growth, resources and environment of the form. The equations can be described as

$$I = P \times A \times T \quad (1)$$

where $T = I/\text{GDP}$. So this equation could be simplified as:

$$I = G \times T \quad (2)$$

where G refers to GDP.

The model has been widely used in the analysis of the driving force of environmental degrading. According to the purpose of this article, we extend IPAT model. We assume GDP and technology will change over time. If energy consumption of a base year is:

$$I_0 = P_0 \times A_0 \times T_0 = G_0 \times T_0 \quad (3)$$

then

$$I_n = G_n \times T_n \quad (4)$$

and

$$G_n = G_0 \times (1+g)^n \quad (5)$$

$$T_n = T_0 \times (1-t)^n \quad (6)$$

where g means the annually growth rate of GDP from the base year to the first n years, and t means the annually decline rate of GDP from the base year to the first n years. Taking (5) and (6) into (4):

$$I_n = G_0 \times T_0 \times (1+g)^n \times (1-t)^n = G_0 \times T_0 \times (1+g-t-gt)^n \quad (7)$$

Table 2
The achievement of China's "Eleventh Five-year Plan" of reducing energy consumption and pollutants emissions in 2006–2008.

	Energy consumption of unit GDP	Total emissions of major pollutants	
Objection of Five-year Plan	Cumulative reduction of 20%	Cumulative reduction of 10%	
Achievement in 2006–2007	Cumulative reduction of 5.38%	–	
Ratio of achievement in 2006–2007	26.90%	SO_2: 32%	COD: 22%
Achievement in 2006–2008	Cumulative reduction of 10.08%	Reduction of 8.95%	Reduction of 6.61%
Ratio of achievement in 2006–2008	50.40%	89.50%	66.10%

Source: Calculated according to "Eleventh Five-year Plan", report of NDRC in China.

Table 3
Values of *GT*.

Year	*GT*	Year	*GT*
1986	0.0123	1998	−0.0175
1987	0.0257	1999	0.0240
1988	−0.0228	2000	0.0225
1989	−0.0342	2001	0.0175
1990	−0.0311	2002	0.0506
1991	−0.0076	2003	0.1270
1992	−0.0057	2004	0.0840
1993	−0.0409	2005	0.0705
1994	−0.0713	2006	0.0562
1995	−0.0370	2007	0.0163
1996	0.0026	2008	0.0591
1997	−0.0131		

Source: Calculated from "China Statistical Yearbook" (1987–2009).

If $g - t > gt$, then environmental impact increases year by year; $g - 1 = gt$, environmental impact will constant; $g - t < gt$, environmental impact decreases year by year. *GT* is defined as indicator to measure environmental impact, and:

$$GT = g - t - gt \tag{8}$$

According to this method, we calculated the annual added values of GDP and annual decline rates of energy consumption, in which added values of GDP are derived from the calculation of constant price in 1980 and decline rates of energy consumption are derived from tons of standard coal unit energy consumption (see Table 3).

For the purpose of visibility, we have change of the values of *GT* shown in Fig. 1.

As showed in Fig. 1, from 1986 to 2001, the values of *GT* fluctuates in a relatively stable condition, while some negative values appear from 1988 to 1998, which means the impact of economic development on environment tend to decrease year by year, and economic development is harmonious with environmental protection. The relationship of economic growth and environmental protection was considerable disharmonious since 2002, in which the *GT* values reached the period top of 0.1270 and declined gradually from 2004 to 2008. Because of the international financial crisis starting in 2008, China expanded investment of infrastructure once again in order to ensure its rapid economic growth, in which the efforts of environment protection relegated to secondary position and the value of *GT* rebounded to 0.0591.

According to the growth rates in all years, we figured out that the average growth rate of GDP in 1985–2008 is 0.1012, while the average decline rate of energy consumption is 0.0889 over the same period, in which the total *GT* value is 0.0033. In the course of fast development of economy, China has not give up the efforts of energy conservation and environmental protection.

5. Policy recommendations

How to maintain rapid economic growth, reduce energy consumption and protect the environment simultaneously will be what China has to confront. Perhaps the step towards the preservation of our environment for the people of the future is to adopt the "green accounting" standards that translate socially and environmentally responsible behavior into monetary terms. Besides, some recommendations are given as follows.

5.1. To develop recycling economy continuously and develop a number of recycling projects in favor of energy conservation

The waste heat from China's building materials and metallurgy industry makes up more than 30% of total fuel consumption, while chemical industry, machinery, paper making, textile and other industries are also more than 10%. Sources of the waste heat mainly derives from industrial exhaust heat, high temperature products and slag waste heat, the cooling medium heat, the disposable heat generating in chemical reaction process, combustible gas, waste water, waste heat and waste gas, and heat of waste water. For example, it can reduce 30–40% coal-fired heating by means of making full use of carbon black tail gas to fire boiler and the waste heat from power generation to heat.

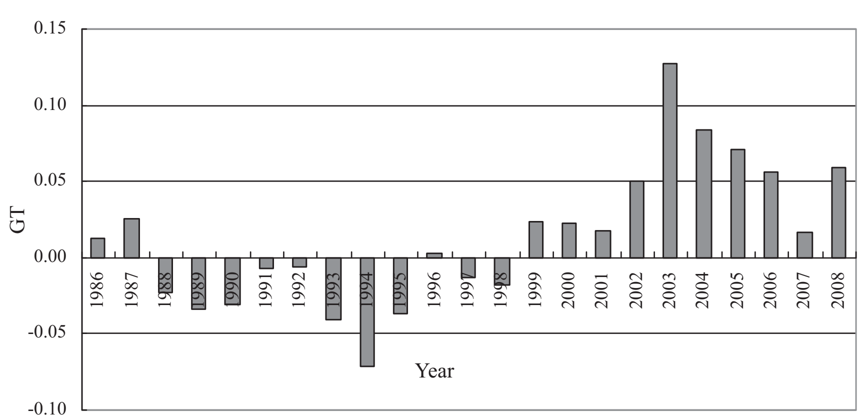


Fig. 1. Change of the values of *GT*.

5.2. To promote technological progression in the process of economic development, and constantly accelerate the energy-saving

Currently, China's pursuing of new industrialization has provided opportunities for saving energy via technology. However, with the outbreak of the international financial crisis, energy-intensive projects were added to in some provinces of China to ensure rapid growth, which in turn have challenged energy conservation since 2008. Therefore, it is imperative to make further planning of high energy-consuming equipment upgrading and establish new mechanisms such as energy-saving equipments leasing and others. China must strive to accomplish the task of eliminating high energy-consuming and outdated equipment, being industrial boilers, furnaces, motors, fans and pumps, in a relatively short period of time. Furthermore, the special planning of transforming the electronic information technology for high-energy-consuming equipment, including motors, boilers, internal combustion engines, fans, pumps and other key energy-consuming equipment, will provide society with high efficient and energy-saving equipment and products.

5.3. To strengthen enterprise management and constantly promote the energy-saving in production process

Enhancing the management level of Chinese enterprises is likely to contribute to saving energy. For instance, enterprises can accomplish the purposes of energy-saving through education, training and other means, which will enhance employees' awareness of energy conservation and improve the ability of energy-saving among staff; hire experts to conduct energy audits, make energy-saving plans, look for problems and weaknesses existing in the energy use so as to take measures of taping the energy-saving capability and search for the direction to save energy; participate in the certification of measuring management system and measurement validation to establish and perfect energy metering management network and energy management systems of the raw materials, production processes and the whole product routine, reasonably select energy measuring equipment and take effective control of the measurement process to ensure that energy metering data is traceable, true and accurate, as well as the reduction of waste of energy caused by the weak energy measurement. A statistical monitoring indicator system of energy, in which the approved quota is decomposed to each energy-consuming sector and vertical management and dynamic supervision can be implemented, may also be set up to meet the multi-level needs in a company. At the same time, it's necessary to form an organic network of accounting oversight, with the fixed share expended to teams, groups, workshops, and sites.

5.4. To speed up industrial restructuring of low-carbon economy

China needs to further strengthen the awareness of energy conservation among its people through the low-carbon economic development policy and take energy efficiency indicators as important quantitative indicators. These should be carried out through the industrial development strategy, planning, project introduction and project design, and acceptance indicator system. Only by strengthening the demonstration and assessment of new projects' energy-conservation, and improving energy-using levels to reduce energy consumption from the source, can China's industry be promoted to the direction that is beneficial to sustainable development. In addition, to achieve these objections needs to adjust the investment structure, raise the industry access standards, strictly enforce high starting-point access for new projects, especially energy-intensive ones, curb the blind development of high energy-consuming industries, develop a mandatory energy efficiency labeling system and set the minimum energy efficiency standards of the main energy-using products, and establish the market access system of end-use products gradually. Meanwhile, it's advisable to encourage high energy-efficient enterprises to merger those low energy-efficient enterprises in order to get intensive production-using energy. It is also important to encourage small enterprises to conduct rational planning, built industrial parks, and develop system-improving management on centralized energy supply to increase the efficiency of energy use.

6. Conclusions

In this article, together with the extended IPAT equation and energy-efficient model, empirical results based on the analysis of China's energy supply and demand and the status quo of energy consumption, show that China's rapid economic growth and energy consumption have a very strong association. The results are coherent with some scholars' results [14], and China is subject to tremendous pressures for mitigating climate change issues [15]. To develop recycling economy continuously, to develop a number of recycling projects in favor of energy conservation, to promote technological progression in the process of economic development, to constantly accelerate the energy-saving, to constantly promote the energy-saving in production process, and to speed up industrial restructuring of low-carbon economy are inevitable choices for China.

The Chinese policymakers have noted the importance of renewable energy for curbing carbon emission [16]. Meanwhile, the wider adoption of green accounting standards would induce the unprecedented growth of the renewable energy sector, because it will promote investment into renewable energy attractive for investors [17]. Energy consumption has become a focus and hot issue towards China's economic development for a long time. On the one hand, energy has become an important material foundation of sustainable development of society and economy in China; On the other hand, because the use of energy is the major source of environmental pollution, how to improve the efficiency of energy use and reduce environmental pollution caused by energy is an important issue to be resolved for Chinese governments. In China, to seek and develop Renewable and Sustainable Energy is the solution in the long run.

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